Multidisciplinary Optimization of a Transonic Truss-Braced Wing Aircraft using Aviary

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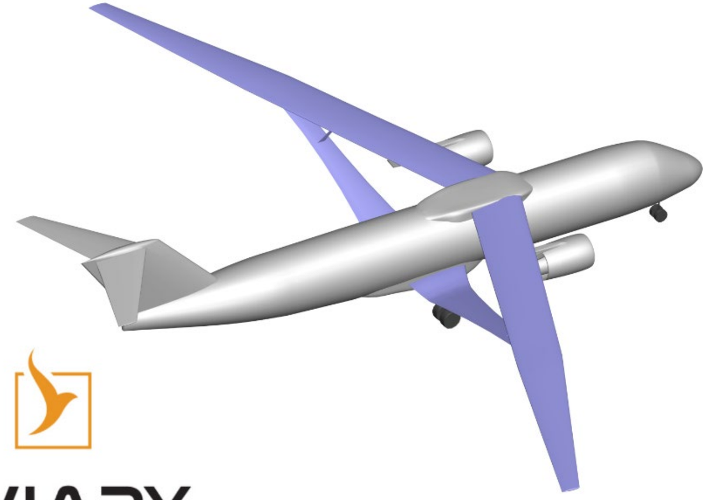


openMDAO

AVIARY

This talk will cover:

- Recent work in aircraft optimization at GRC
- Transonic Truss-Braced Wing (TTBW) example
- Problem setup
- Results
- Challenges

What aircraft have we previously optimized?

- Tiltwing Turbo-Electric

Aviation 2019

Multidisciplinary Optimization of a Turboelectric Tiltwing Urban Air Mobility Aircraft

Subsystems Optimized: Propulsion, Electrical, Trajectory, Aerodynamics, Mass

- Quadrotor Urban Air Mobility

Aviation 2020

Multidisciplinary Optimization of an Electric Quadrotor Urban Air Mobility Aircraft

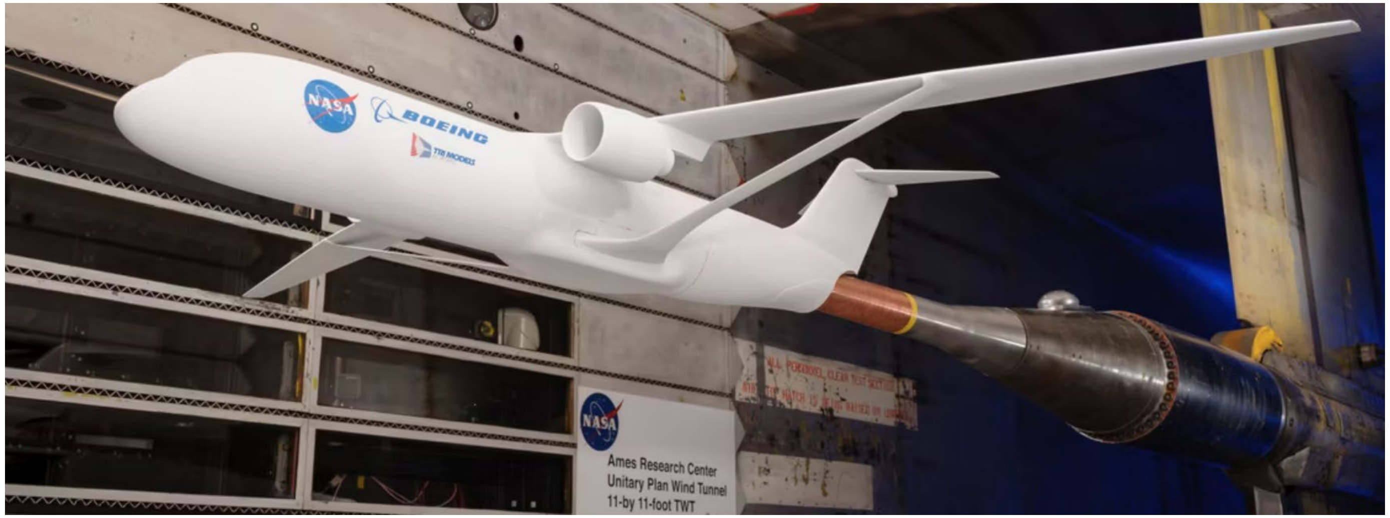
Subsystems Optimized: Electrical, Thermal, Trajectory, Mass, Aerodynamics

How were these aircraft modelled?

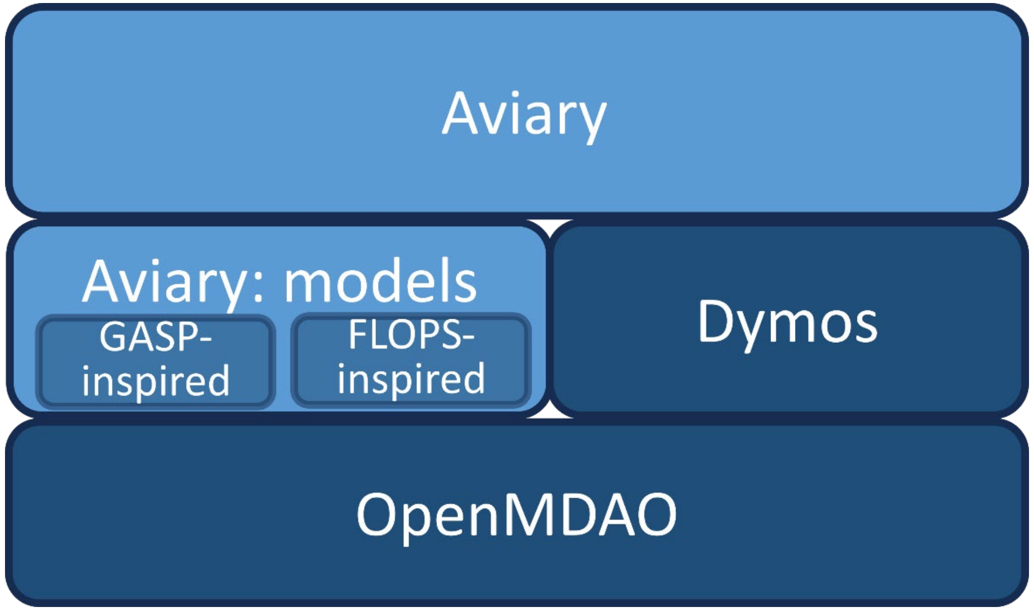
- Subsystems individually assembled in openMDAO
- System level analysis performed with OpenMDAO and Dymos
- **Challenges:**
  - One-off implementation required lots of setup and expertise
  - Subsystem models were not open source
  - Focused on optimization more than analysis

The first application of Aviary to an aircraft modelling problem: TTBW Aircraft

- Subsystems included: Aerodynamics (VSPAERO), Mass (FLOPS-based), Mission (Height-Energy), Propulsion (pyCycle),
- Two configurations: Electrified Climb Assist vs. Non-electrified

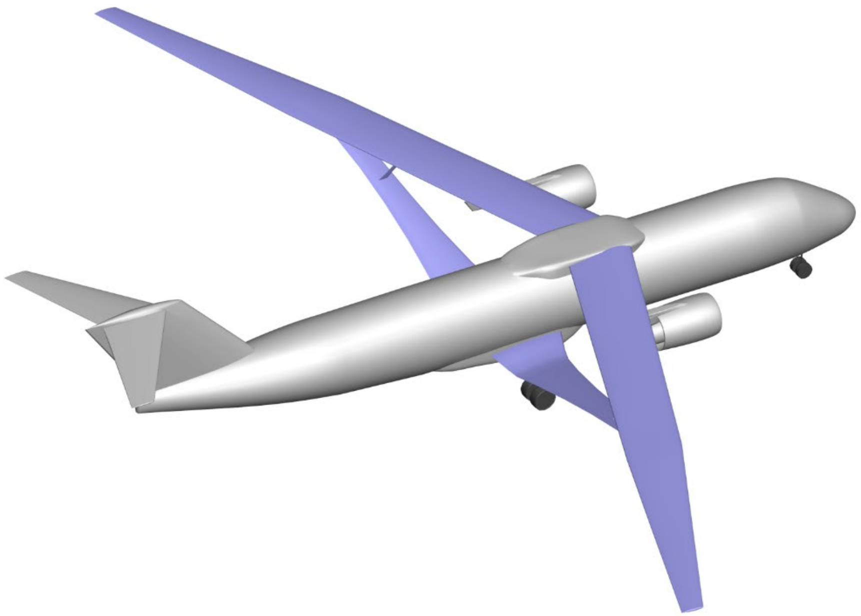


Ames Unitary Plan Wind Tunnel



Non-Electrified TTBW Example Problem

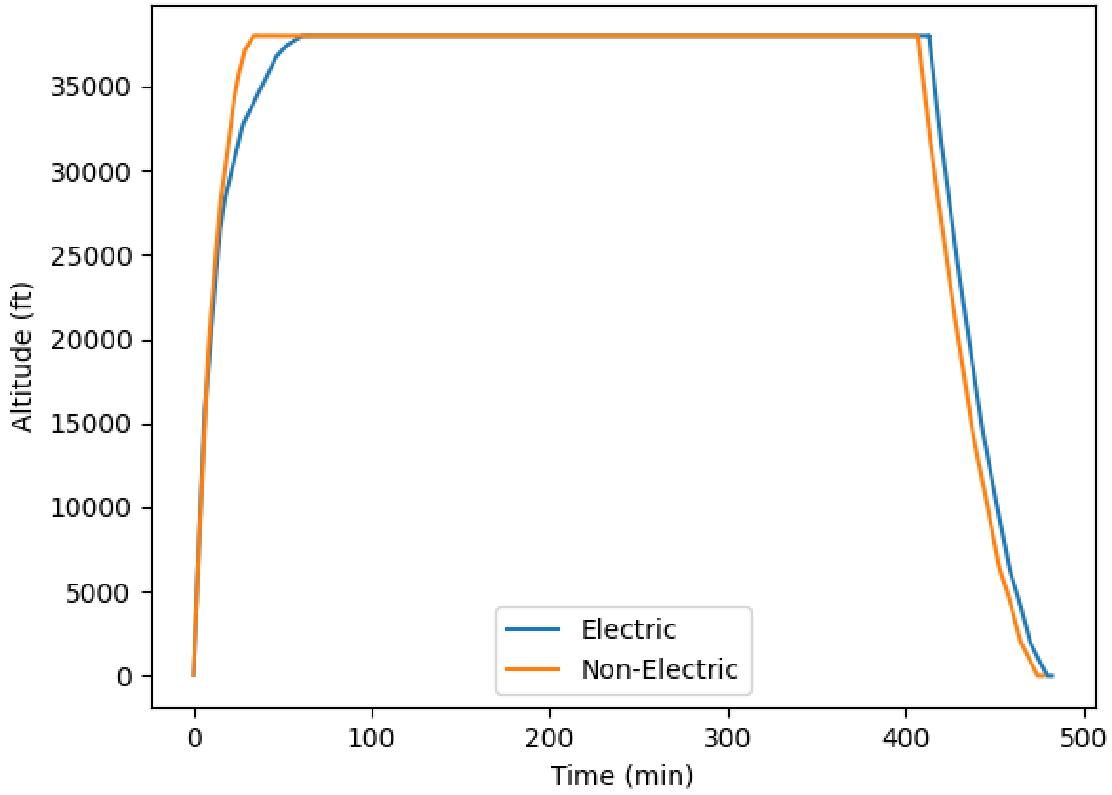
	Variable or Function	Size	Discipline
minimize	Fuel Burn	1	
with respect to	Design mass flow	1	Gas Turbine
	Gross Takeoff Mass	1	Weights
	Climb Duration	1	Trajectory
	Cruise Duration	1	
	Descent Duration	1	
	Altitude	24	
	Mass	24	
	Range	24	
	Velocity	24	
	Engine Throttle	9	
	Acceleration	9	
subject to	Mass Residual	1	Weights
	Throttle Constraints	24	Propulsion
	Pseudospectral Constraints	155	Trajectory

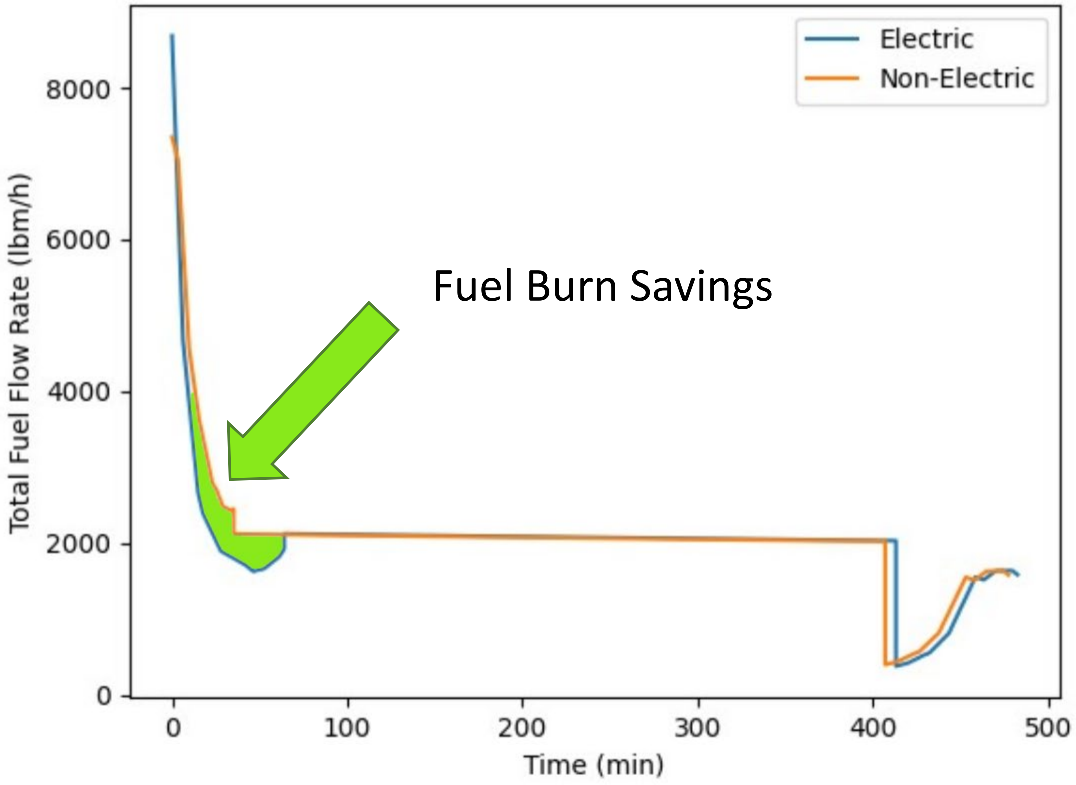


Electrified TTBW Example Problem

	Variable or Function	Size	Discipline
minimize	Fuel Burn	1	
with respect to	Design mass flow	1	Gas Turbine
	Gross Takeoff Mass	1	Weights
	Nominal Energy	1	Electrical
	Motor Max Power	1	
	Climb Duration	1	Trajectory
	Cruise Duration	1	
	Descent Duration	1	
	Climb Electric Shaft power	9	
	Altitude	24	
	Mass	24	
	Range	24	
	Velocity	24	
	Engine Throttle	9	
	Acceleration	9	
subject to	Mass Residual	1	Weights
	Throttle Constraints	24	Propulsion
	Electric Power Constraints	14	Electrical
	Pseudospectral Constraints	155	Trajectory

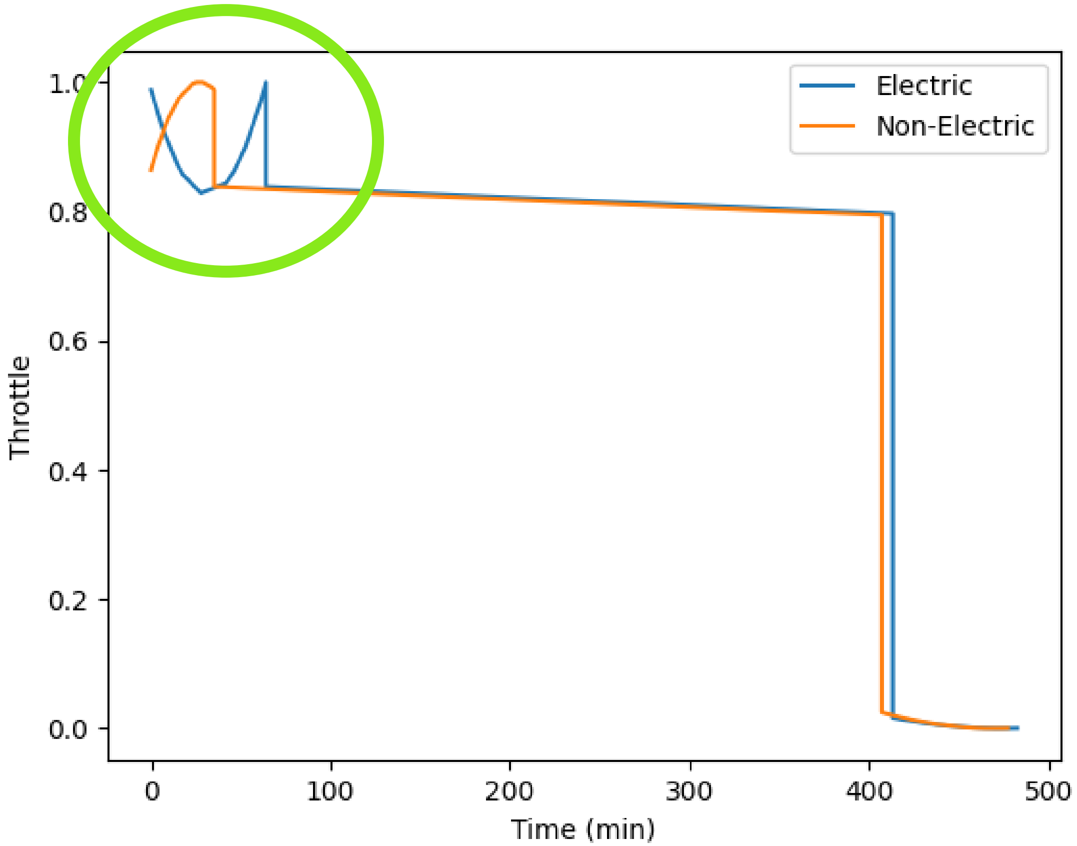
Overall fuel burn in climb decreases with electrical climb assist.

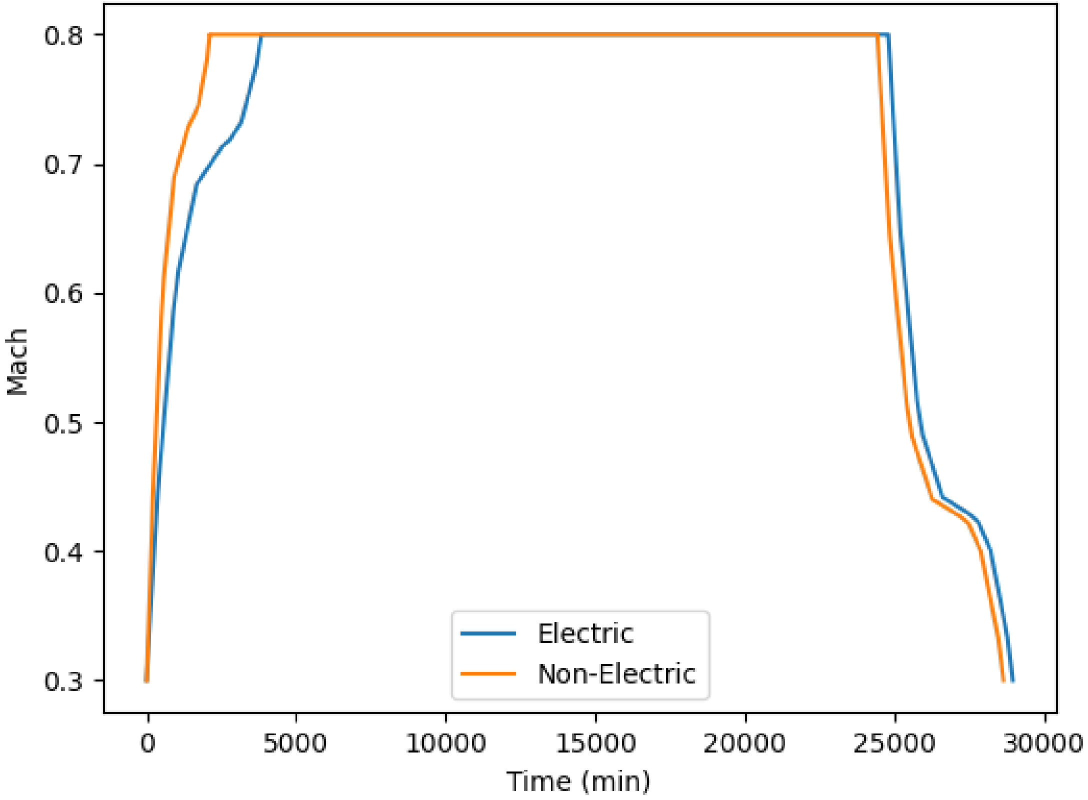




Overall Fuel-Burn Decreased by ~200kg
GTOW increase by ~700kg

Throttle control varies significantly between two cases.





Optimization results based on overly optimistic battery energy density

Optimization	Fuel Burn (kg)	GTOW (kg)	Battery Mass (kg)	Battery Enrgy (kWh)	Battery Energy Density (Wh/kg)	Motor Max Power (kWh)
Non-Electric	7542	61941	0	0	N/A	0
Electrified	7350	62692	1221	611	2000	746

Optimization	TOC Overall Pressure Ratio	TOC Bypass Ratio	TOC Net Thrust per Engine (N)	TOC Mass Flow (kg/s)
Non-Electric	57.8	13.6	14700	148
Electrified	57.8	13.6	14700	148

Challenges

- Successful optimization requires careful selection of initial conditions, design variables, and control order
- 2nd order controls appear too low for this analysis and results change as control order becomes larger but computation time increases
- Electrical system can have lower GTOW than non-electric if control order increases
- 300ft/min climb constraint in cruise is primary driver of engine size
- The team was working on building Aviary while also trying to complete the TTBW simulation

I want to build my own aircraft optimizations using Aviary, how can I do that?

- Clone the Aviary Repo: https://github.com/OpenMDAO/om-Aviary
- Make subsystems from physics you already understand
- Piece together multiple subsystems to form a system-level optimization
- Videos: https://www.youtube.com/@OpenMDAO

Questions?

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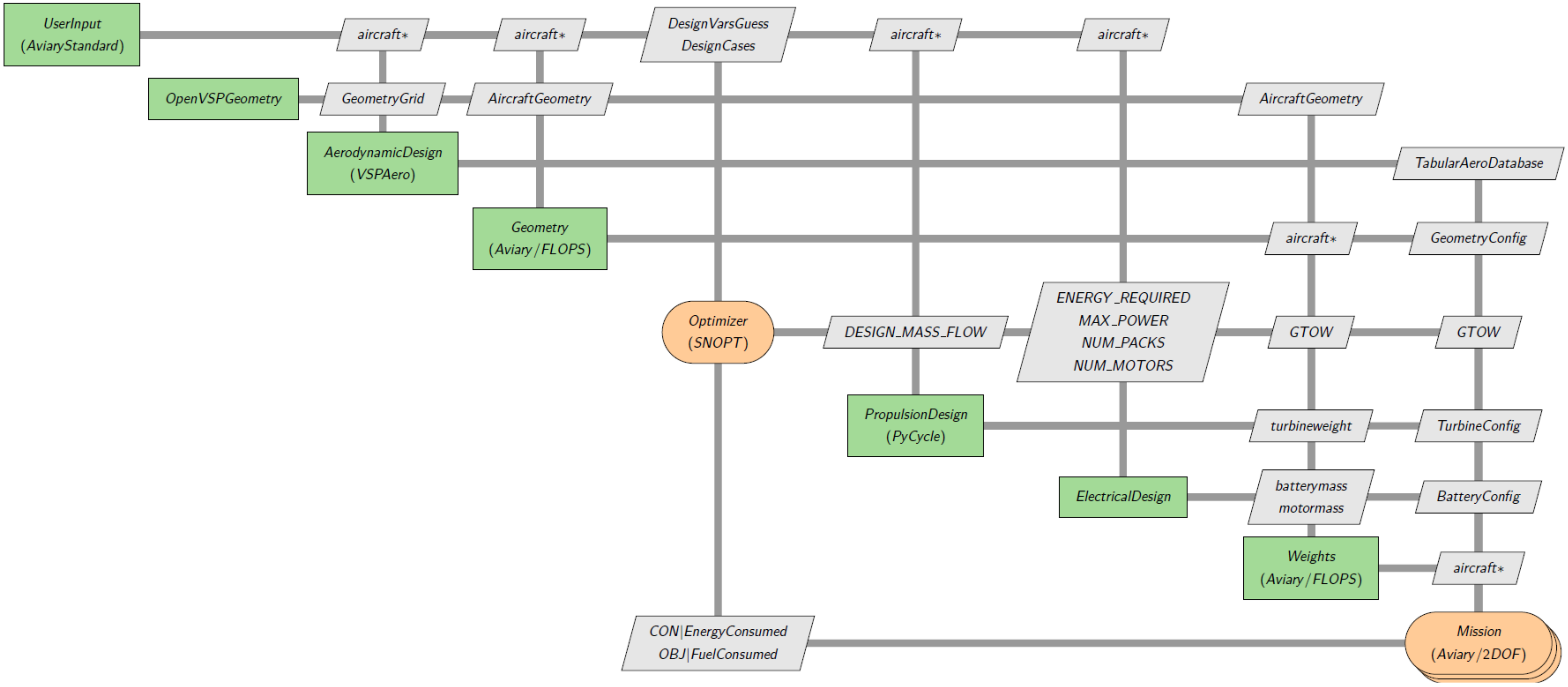
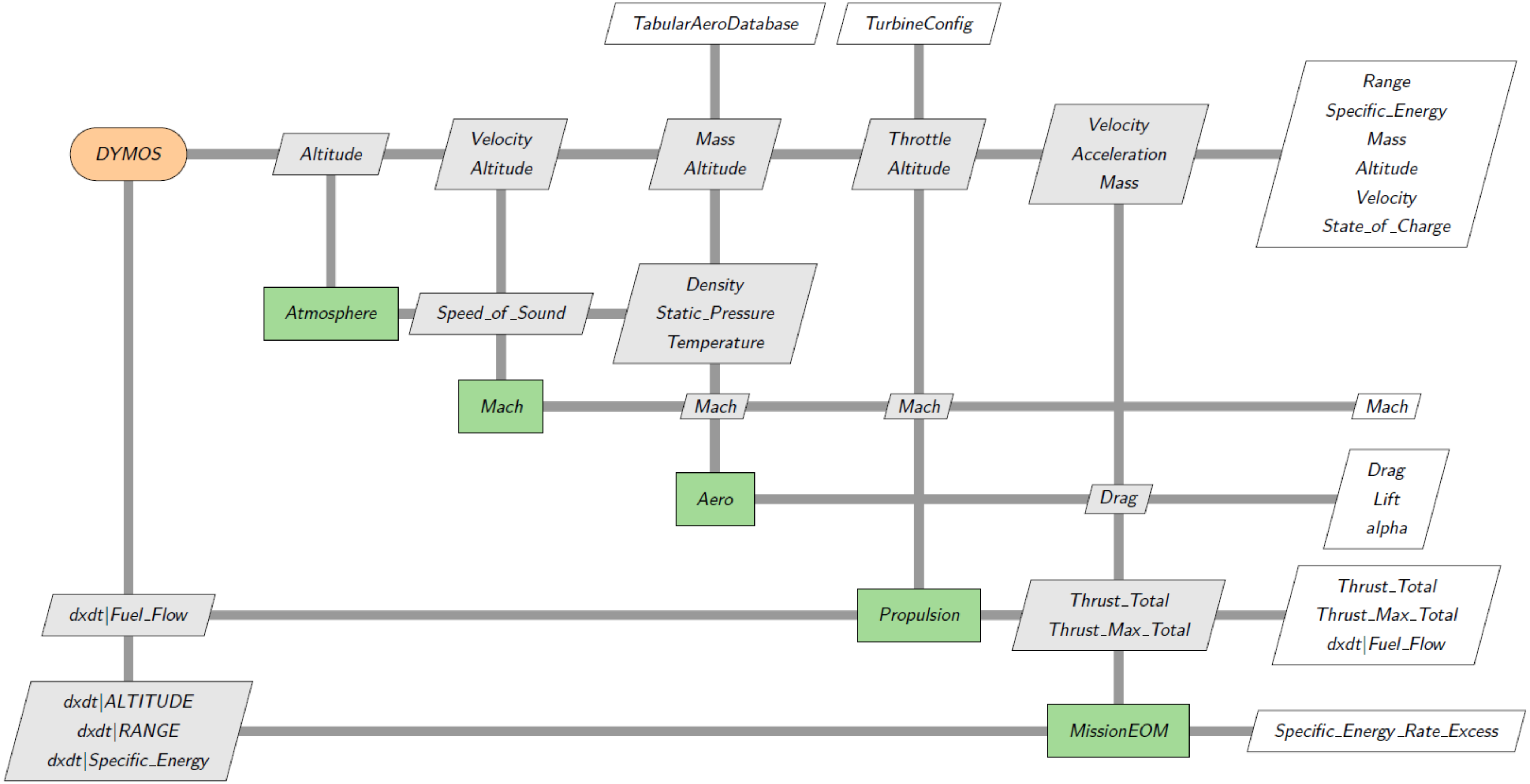
Backup

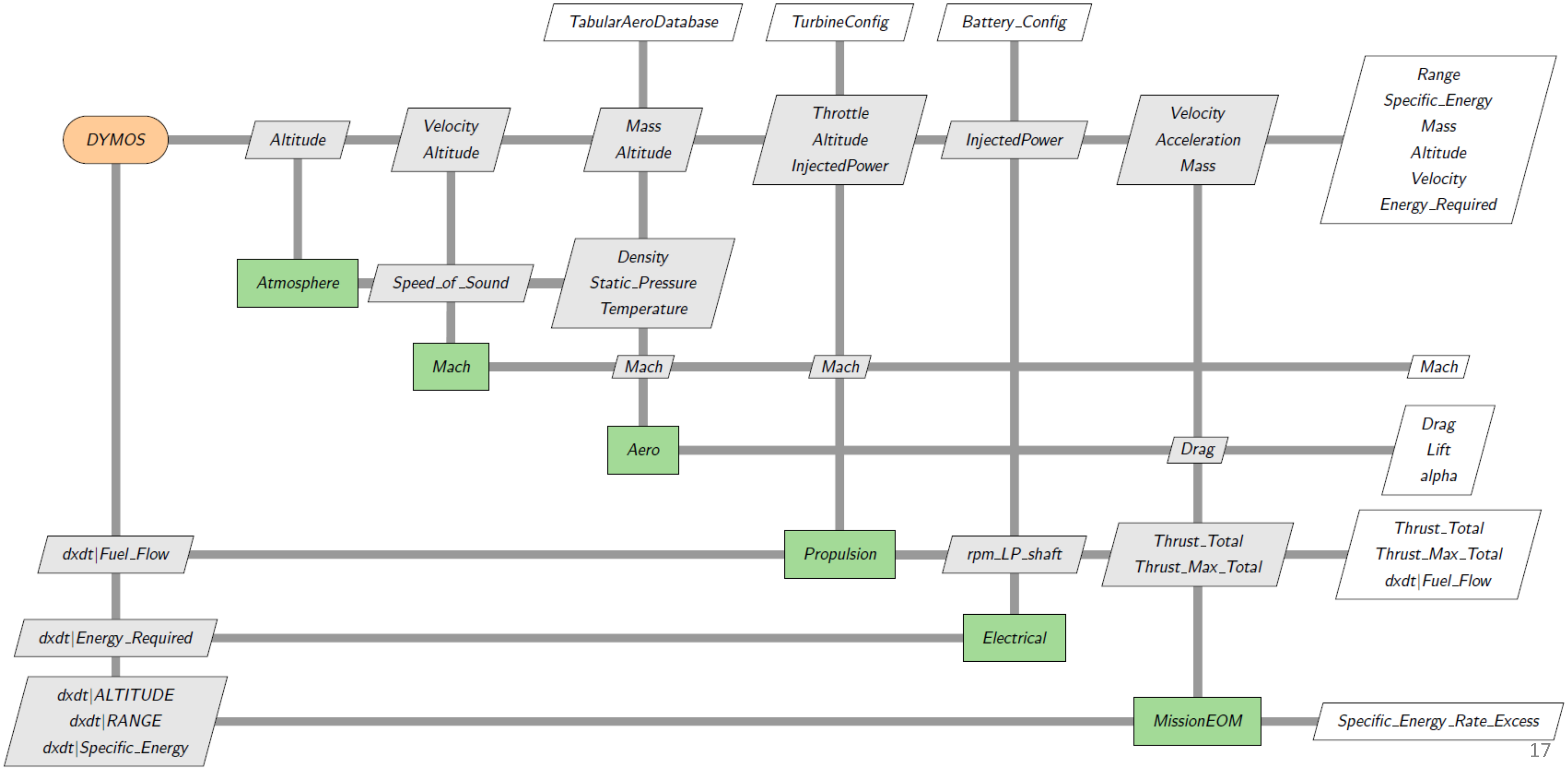
XDSM of the TTBW, Pre-Mission



XDSM of non-electrical mission



XDSM of electrical mission



What purpose-built tools does NASA have to model preliminary design of aircraft?

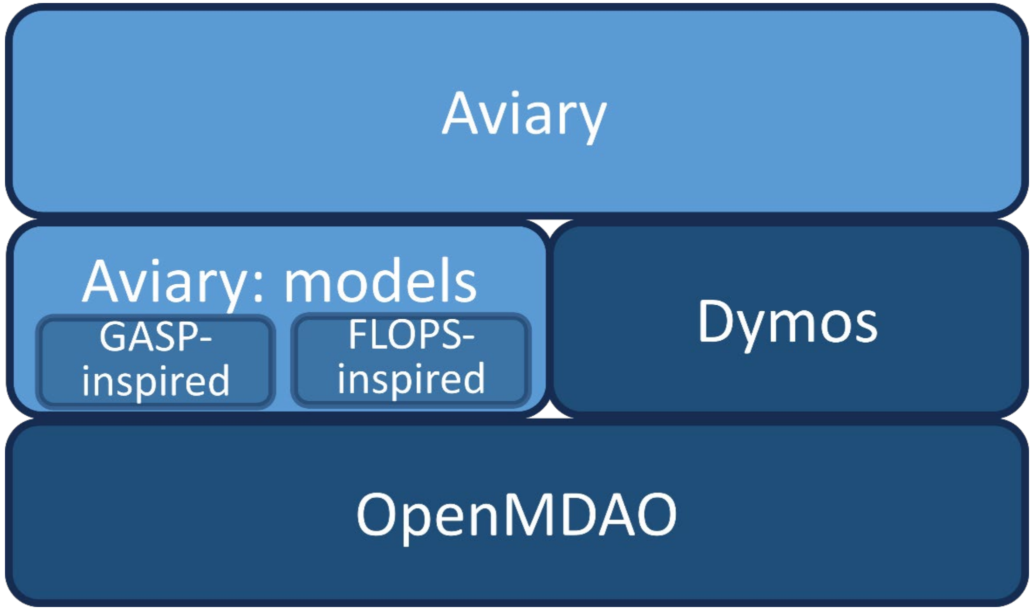
- GASP – General Aviation Synthesis Program (Fortran)
- GASPy – OpenMDAO/Python implementation

- FLOPS - Flight Optimization System
- LEAPS
- LEAPS 2.0 – OpenMDAO/Python implementation

AVIARY

Introducing Aviary, an open-source tool for preliminary aircraft analysis and optimization.

- Aviary is a preliminary design tool for aircraft capable of modeling traditional and novel designs.
  - Built on top of OpenMDAO & Dymos
  - Open Source
  - Easy-to-follow examples
  - Analysis
  - Optimization
  - Low-fidelity subsystems included
  - Bring your own higher fidelity subsystems



Optimization Problem Description

- Starting at Mach 0.3 and 15ft altitude climb to 38,000ft and Mach 0.8
- Steady-Level Cruise at Mach 0.8 and descend back to 0ft and Mach 0.3
- Distance travelled 3412 nautical miles.
- Subsystems that are being optimized:
  - Turbine Engine design mass-flow
  - Gross Takeoff Weight (GTOW)
  - Electrical Motor & Battery Size (electrified optimization only)
- Objective of optimization: minimize Fuel Burn

Future Direction for Aviary

- Support an optimization ecosystem where users can bring their custom models and integrate them into an aircraft optimization tool of their choice.
- Aviary "Garage" of pre-designed aircraft that users can draw from for inspiration and examples
- Examples of how to easily integrate external subsystems: NPSS, OpenAeroStruct, CCBlade, Structural Analysis, etc.
- Stronger collaboration with other optimization tools (CSDL and others) and easier ability to integrate external / remote analysis performed in non-python code bases (Philote)

References

- Multidisciplinary Optimization of a Turboelectric Tiltwing Urban Air Mobility Aircraft – Hendricks et al.
- Multidisciplinary Optimization of an Electric Quadrotor Urban Air Mobility Aircraft – Hendricks et al.
- Advancement of the General Aviation Synthesis Program Using Python to Enable Optimization-Based Hybrid-Propulsion Aircraft Design – Lyons et al.